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A Historical Review of the Need for Military Toxicology and the U.S. Army's Response

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"If men could learn from history, what lessons it might teach us!"

Samuel Taylor Coleridge
(1772–1834)

Is there a discipline called "military toxicology" that is different enough from the standard practice of toxicology to deserve a distinctive label, or is military toxicology merely the usual practice of toxicology on a military installation or on behalf of the military? To answer this question, I will historically review the requirements for toxicological assessments that occurred in the United States military services and a few foreign military services. How the U.S. Army fulfilled its need for toxicological studies through the establishment of several laboratories is discussed, followed by some thoughts for the future.

Introduction

The Early Years

Considering a traditional definition of toxicology, that is, "the art and basic science of poisons," and reflecting on how this discipline may have related to earlier armies, one will almost certainly conjure up ideas of assassination attempts and poisonings of troops.(1) Examples of both occured in the United States. One was probably accidental, the other intentional.

In the late 1670s, Nathaniel Bacon led a rebellion against the Colonial Governor in Jamestown. A thousand English troops were sent to suppress the rebels; however, by the time they arrived, Bacon had died of a fever and the Governor was gathering the other insurgents. The troops made camp, stood by while trials and executions were carried out, and foraged for food. One group returned with the foliage from a leafy plant, which they cooked as a mess of greens. What followed was described as "a very pleasant Comedy" performed by "natural fools." Recorded observations included "snearing," "pawing," "kissing," and "nakedness" that lasted 11 days and passed without any of those affected remembering what had occurred. They had consumed the leaves of the thorn apple, *Datura stramonium*, which contains belladona alkaloids. Because of this incident, the thorn apple became known as the Jamestown weed, a name later corrupted to jimson weed.(2)

The second incident was directed at George Washington. Thomas Hickey, a member of Washington's guard and a Tory sympathizer, plotted with the daughter of a New York City tavern keeper to add an unknown poison to Washington's food. The woman apparently had a change of heart and whispered a warning to her guest while serving him peas. The peas were not eaten. Hickey later attempted to form a secret Tory corps within the rebel army and participated in planning for the burning of New York City and the assassination of General Washington by stabbing. Thomas Hickey was hanged on 28 June 1776, distinguishing himself as the first American soldier to be executed.(2)

The art of toxicology also was used very early in history to directly improve the warrior's offensive capability in combat. Arrows with poisoned tips probably appeared on the battlefield before 1500 B.C., since the Ebers papyrus of approximately the same period contains a recipe for aconite, an arrow poison used by the ancient Chinese.(1)

The three episodes above are interesting but provide little insight into why the modern military developed a need for toxicological expertise. Certainly, the potential contamination of food rations with toxins remains an important military concern, and the introduction of toxic chemicals onto the battlefield in the form of poisoned arrows might be considered a harbinger of the chemical warfare of World War I. However, the massive military machines with incredible firepower that began appearing in the latter nineteenth century, and the dispatching of U.S. forces to the far corners of the world, to the depths of the ocean, and beyond the earth's gravity introduced questions about toxic hazards that challenged the most expert toxicologists.

To fully appreciate the importance of the milestones discussed below, one must expand the traditional definition of toxicology to include the contributions made to hazard identification and communication, standards development, and the formulation of policy regarding public health, the workplace, and the general environment. Several significant events are summarized under the categories of chemical warfare, conventional munitions, toxicity of materials, and military enclosed spaces.

Chemical Warfare

Early warriors and military minds of the American Civil War pondered the use of highly effective chemical weapons on the battlefield; however, the world's chemical expertise was undeveloped and could not support the concept. Additionally, the attitude that chemical warfare was repugnant probably existed in antiquity. A Latin quotation, and perhaps the first prohibition against the military use of chemicals, reads: "War shall be waged with weapons, not poisons." This situation began changing in the decades preceding World War I. The European chemical industry experienced extraordinary growth, with Germany emerging as a leader. Basic work on dichloroethylsulfide, which we would later recognize as "mustard," was conducted by the English chemist Guthrie as early as 1860. He described its blistering effect on skin when applied as a liquid. The Swedish chemist Scheele produced chlorine, arsenic, and hydrogen cyanide. By the turn of the century, these chemicals were available in large quantities and military applications were being considered seriously. Concern that these substances might be used in anger prompted nearly all the European states to adopt in 1907 a prohibition against the use of poisons in warfare.[3–5]

Restraint in the use of chemical weapons lasted only 8 years. Germany entered World War I with plans that called for only a few months of intensive warfare. The winter of 1914–1915 brought about serious depletion of ammunition stocks and Germany looked to ways of mobilizing national industries behind its military forces. The French had used tear gas as early as August 1914 and the German chemical industry was very powerful. The choice seemed obvious to everybody except the Allies, who seemed to think it would never happen. On April 22, 1915, at Ypres, Belgium, the Germans launched their first gas attack using chlorine. Attacks with phosgene, mustard, and a number of other agents (including the pulmonary irritant chloropicrin and the vesicants chlorarsine and bromoarsine) followed.[3–5]

The Allied military physicians did not know how to treat gas casualties. The U.S. observed the events occurring in Europe but did not seriously investigate the physiology, pathology, and therapy of chemical warfare injury until 1917, the year we entered the hostilities. When studies were finally initiated, these were directed by the medical and the pharmacology and toxicology sections of the U.S. Army Chemical Warfare Service, in collaboration with the U.S. Bureau of Mines; Yale University; American University; Western Reserve University; and the Royal Engineers' Experimental Station, Porton, England. Considerable work was done that contributed to the development of toxicological methodology. For example, various exposure chambers were designed and built, the strengths and weaknesses of different animal models were studied, and considerable emphasis was placed on finding ways to evaluate pulmonary and ocular toxicity.[5,6]

In World War I, almost 100 thousand people were killed and more than 1 million casualties were inflicted because of the use of poison gas. The 1925 Geneva Protocol banned the use of poison gas but permitted its development, production, and storage. Unfortunately, the use of chemical warfare agents has continued. Italy used it against Ethiopia (1935–1936); Japan used it against the Chinese (1939–1944); and Iraq used it against Iran and against its own Kurdish population (1983–1988). In 1969, President Nixon unilaterally halted the production of chemical weapons in the U.S. This action resulted in large stockpiles of chemical warfare agents that would be left in place, to deteriorate and to eventually create a major waste disposal problem. The 1986 Defense Authorization Act required the destruction (demilitarization) of the aging munitions and agents. In keeping with the U.S. position that a chemical weapons capability deters an enemy poisonous gas attack, the 1986 Act also approved production of a new kind of chemical weapon, the binary system. In the binary system, two components of toxic but sublethal character are manufactured and stored separately. When the weapon (e.g., an artillery shell) is fused, separate containers of each component are installed. On firing, the separate containers rupture and the components mix to reach lethality.[7–10]

Both the planned destruction of old chemical warfare munitions and the production of the binary system created many new questions and issues, and they echoed many old questions and issues about chemical agent toxicity. From the first use of chemical warfare agents in World War I to the present, the U.S. Army has never stopped laboratory work on chemical agents, although the emphasis has changed over time. The concerns that have fueled this research have resulted from the possibility of chemical agent exposure with armed conflict; terrorist activities; the destruction of our aging chemical stockpile; the accidental unearthing of old, forgotten burial sites; and the production of the binary system.[11] Beginning with World War I, the Chemical Warfare Service had both medical and research sections. This arrangement continued until 1979 when the Biomedical Laboratory of the U.S. Army Chemical Systems Laboratory, Edgewood Area of Aberdeen Proving Ground (APG), Maryland, was transferred to the U.S. Army Surgeon General, thereby creating a sharp distinction between Chemical Corps research and U.S. Army Medical Department research into antidotes and the defensive aspects of chemical warfare. The two laboratories that resulted were the Toxicology Division of the U.S. Army Chemical Research, Development and Engineering Center (CRDEC), APG, Maryland, and the U.S. Army Medical Research Institute of Chemical Defense (U.S. AMRICD), which is also at APG.[5,11–13]

Conventional Munitions

It was not until the eleventh century A.D. that propellants and explosives as we know them began to emerge. Using potassium nitrate (saltpeter), sulfur, and charcoal, the Chinese developed explosives that sometimes burned and sometimes exploded. Their early military use of this material probably included experimentation into propelling objects from bamboo tubes; however, the Arabs were given credit for inventing the first gun in 1304.[14]

Knowledge about the mixture of saltpeter, sulfur, and charcoal, or "black powder," spread throughout the western world between the thirteenth and seventeenth centuries. In the colonies, powder making was initally conducted in a primitive fashion as a small cottage industry. Later, powder mills were constructed, but there were few innovations in the powder industry until the mid-nineteenth century, when a new military explosive called guncotton appeared in America. This nitrated cotton, invented in Switzerland, was far ahead of its time and was rejected by American manufacturers because it was too costly to produce and its strong gases ruined gun barrels. Later, in 1866, Alfred B. Nobel perfected a superior explosive after experimenting with mixtures of nitroglycerin and various materials including black powder, charcoal, brick dust, and wood dust. He named his new explosive dynamite. Dynamite was primarily a commercial explosive because it was extremely effective in breaking up rock and ore and greatly increased production in the mining, excavating, and oil drilling trades. Nevertheless, the rapidly developing dynamite industry demonstrated several features that signaled major changes in the manufacture of military explosives and propellants. These included a relatively safe explosive, affordable cost, and an explosive that could be modified to fit a variety of different applications. As for black powder, the Spanish–American War (1898) was the last major conflict in which it was used in large quantities. Black powder continued to be employed for special applications, e.g., in primers and fuses; however, World War I (1914–1918) was fought with a new generation of explosives.[14]

Prior to World War I, Americans had been heavily reliant on the German chemical industry. The U.S. industrial base contained very little expertise in the production of many of the chemicals needed in wartime. Therefore, the U.S. industries, especially those dealing with coke by-products, had to realign to produce dyes, aniline, and nitric acid, which was critical to the production of munitions. The leaders of these industries expressed concern about preventing explosions but had no interest in the toxicity of industrial chemicals, particularly unfamiliar ones like picric acid and trinitrotoluene (TNT). Dr. Alice Hamilton, the pioneer of American occupational medicine, inspected many munitions plants for the U.S. Department of Labor. She sometimes located the industrial site "by the great clouds of yellow and orange fumes, nitrous gases, which in those days of crude procedure rose to the sky from picric-acid and nitrocellulose plants. It was like the pillar of cloud by day that guided the children of Israel." At other times, "canaries," workers stained yellow with picric acid, led her to the plant.[15]

Both Hamilton and U.S. Army sources documented the morbidity and mortality from occupational diseases that were attributed to exposures in the U.S. munitions industries. Exposure to oxides of nitrogen and TNT were thought to account for most illnesses and deaths due to toxicity. The Army reported that in World War I there were 230 fatalities (presumably due to occupational diseases) per billion pounds of explosives manufactured.[15,16]

Hamilton considered "nitrous fume poisoning" to be an engineering problem that manufacturers eventually corrected. However, TNT poisoning was a different matter. Acccording to Dr. Hamilton, the English knew about the problem of skin absorption with TNT exposure, and English manufacturers paid attention to the need for plant cleanliness and personal hygiene in the workplace, to include having washable working clothes and showers. Manufacturers in the U.S. did not do these things. In England, there was a wealth of clinical information concerning TNT poisoning, but American physicians apparently did not know what to look for, were indifferent, or were secretive.[15]

Alice Hamilton attacked the explosives industry in several ways, including 1) causing the National Research Council to appoint an expert committee to act as a consultative body and 2) working to establish a code to protect TNT workers. The expert committee made it possible for medical students to visit TNT plants and to study exposures and poisonings. Additionally, in April 1919, 5 months after the armistice, a code was published. Unfortunately, the code was voluntary and weaker than the British code.[15]

Dr. Hamilton was a pacifist, but she acknowledged the advancement of industrial hygiene and toxicology in America as a result of World War I: "The war did have a beneficial influence on industrial hygiene. If it increased the dangers in American industry, it also aroused the interest of physicians in industrial poisons. And that interest has never died down, on the contrary it has increased with the increasing complexity of methods of manufacture."[15]

During World War II, in the U.S. munitions industry, 968,000 man-years of operations resulted in 28 occupational disease fatalities (22 from TNT exposure, 3 from oxides of nitrogen, 2 from carbon tetrachloride, and 1 from ethyl ether). These numbers equate to less than three occupational disease fatalities per 100,000 man-years of work or five fatalities per billion pounds of explosives manufactured, a ratio 46 times lower than that observed for World War I.[16]

One significant reason for the large difference in occupational disease morbidity and mortality between World War I and World War II was the establishment of the U.S. Army Industrial Hygiene Laboratory at the Johns Hopkins University School of Public Health, Baltimore, Maryland, in 1942. The laboratory consisted of people skilled in medicine, chemistry, toxicology, industrial hygiene, and engineering. Their mission was to assess occupational health hazards at various industrial facilities supporting the war effort. The laboratory focused on operations in munitions plants, arsenals, and depots, and the associated toxicological issues were addressed by the military services, the U.S. Public Health Service, and civilian institutions. Literature reviews were done to obtain all existing toxicity data on aromatic amino and nitro compounds, which included most explosives, and extensive field and laboratory research studies examined the toxicity of many different types of explosives, including TNT, pentaerythritoltetranitrate (PETN), and RDX (cyclonite). Additionally, the U.S. Public Health Service evaluated stream pollution from explosives plants.[16,17]

History has demonstrated that military planners and weapons developers will never cease in their search for better and more powerful explosives and propellants. However, history has also shown that human health effects must be determined early and appropriate steps taken to protect those who may encounter toxic exposures. Toxicological work in this area has continued to be addressed by the U.S. Army Environmental Hygiene Agency (U.S. AEHA, formerly the U.S. Army Industrial Hygiene Laboratory), APG, Maryland and the U.S. Army Biomedical Research and Development Laboratory (U.S. ABRDL). U.S. ABRDL was established at Edgewood Arsenal, Maryland, in 1972 as the U.S. Army Medical Environmental Engineering Research Unit. In 1974, it was transferred to Fort Detrick, Maryland, becoming the Environmental Protection Research Division of the U.S. Army Medical Bioengineering Research and Development Laboratory. It was renamed U.S. ABRDL in 1986. In 1978, toxicological research needs exceeded the capabilities of U.S. ABRDL, and toxicology studies were initiated at the Letterman Army Institute of Research (LAIR), Presidio of San Francisco, California. In 1988, the toxicological effort at LAIR was discontinued.[17–21]

Toxicity of Materials

The toxicological issues encountered by the military services in World War II rapidly expanded beyond the munitions industry. This was the result of several factors: 1) following World War I, the U.S. chemical and automotive industries experienced tremendous expansion and became suppliers of an incredibly long list of new materials; 2) the expansion of American industry was accompanied by an awareness of the adverse health effects that may result from exposure to chemicals; and 3) the U.S. military in World War II had more people scattered over a wider geographical area than in any other war in history. Uniformed people were coming in contact with chemical compounds that were intended to keep their machines running, to protect their equipment from mildew, and to protect them from disease-carrying insects and pathogenic agents such as malaria. To help deal with the complex issues of product safety and toxicity, a Toxicology Branch was established in the Office of the Army Surgeon General in January 1944. This Branch worked with numerous laboratories and the U.S. Public Health Service to provide the urgently needed toxicological assessments. Substances that were evaluated included fungicides, flame retardants, fuels, cosmetics, plastics, adhesives, alloys, food stuffs, methyl bromide, DDT, and other insecticides, miticides, and repellents including aerosols. Unfortunately, many opinions on the presence or absence of toxic hazards were rendered on the basis of judgement only because the needed scientific data were not available. The toxicological capability of the uniformed services had been overwhelmed. This unfortunate and unacceptable problem was clearly recorded in the medical archives of World War II.[15,16,22–24]

Following World War II, the U.S. military would retain a global posture, tropical infectious diseases would continue to pose serious threats, and the list of new chemicals used in vehicles, equipment and clothing, and applied directly to the skin would continue to grow unceasingly. The last 45 years have demonstrated time and time again that the questions of acute and chronic toxicity associated with the use of these chemicals and the materials which contain them must not only be asked but also must be addressed long before there is human contact through production and use. Today, this work continues on a routine basis at CRDEC, U.S. AEHA, and U.S. ABRDL. Safeguards have been implemented that now require the review of all new items in the Army supply and equipment systems, including toxicological assessment, prior to the time these items are made available to troops in the field.[13,25,26]

Military Enclosed Spaces

"Military enclosed spaces" refers to the uniquely military environment that is most often found on submarines, in armored gun turrets, inside armored land vehicles, and on military aircraft and spacecraft. These distinctive military environments are similar in many respects but different in others. The adverse health effects experienced by military personnel serving in military enclosed spaces became apparent in the World War I era. These were addressed to some degree in World War II. However, the unique exposures of military enclosed spaces did not receive the emphasis they deserved until the U.S. went into a period of intense weapons modernization in the late twentieth century.[25,27–31]

Naval Contribution

Even before Archimedes described the principles of submersion, Alexander the Great is alleged to have used a submersible vessel at the seige of Tyre in 332 B.C. From the time of Alexander to 1900, inventors made submarines and attempted to power them by hand, by steam, and later, by electric batteries and petrol engines. One was even deployed unsuccessfully by the Americans against the British in the Revolutionary War. In the American Civil War, a Confederate vessel, the H. L. Hunley, became the first submarine to sink a warship. This was hardly a victory because the Hunley and her crew also went down in the explosion. The torpedos of the Civil War were attached to a long spar or boom in front of the submarine. The only possible chance for success was for the slow submarine to attack a ship at anchor and to hope for the best in getting away before an explosion occurred. By 1900, several innovations were merged to develop the model for the twentieth century submarine. These included a strong metal hull to withstand great pressure, a self-propelled torpedo that could be launched by the submarine, a gasoline engine for power on the surface, and an electric propulsion system that did not require contact with the atmosphere.[32–34]

Initally, undersea craft had to surface frequently to recharge the batteries. In the 1930s, Dutch naval experts developed the snorkel, which allowed the craft to remain submerged for long periods. (One German U-boat stayed submerged for 69 days.) When necessary, a fan pulled in fresh air and the diesel motors were run under the sea. The internal environment of the submarine before the nuclear age was unpleasant. Submariners described foul, stale air that reeked of diesel fuel and other unpleasant odors, and mildew that covered food, clothes, and bunks. During World War II, there were many reports of reduced effectiveness in submarine crews because of what the Navy called "defective habitability." The following are quotes from U.S. Navy World War II reports:

> "Battery compartment of torpedo flooded during attack, emitting chlorine gas into the boat."
>
> "Lack of air conditioning decidedly had a debilitating effect on crew and slowed their reactions."
>
> "Patrol somewhat handicapped by poisoning (carbon tetrachloride) which affected majority of crew over ten day period."

Carbon tetrachloride was used as a cleaning spray for electric motors. When the motors became hot, it volatilized and produced phosgene.[35,36]

The nuclear submarine made its debut in 1955 and brought with it atmospheric control. Oxygen was extracted from seawater and air scrubbers removed contaminants, but the questions and problems of submarine air quality did not go away. In 1988, after an extensive study requested by the U.S. Navy, the Committee on Toxicology of the National Research Council released a 154-page report on submarine air quality that addressed monitoring and health effects in divers who breathed submarine air under hyperbaric conditions. As we have observed in the past, naval weapons developers will continue to modify and to introduce new materials into submarines. It would be absurd to think that submarine air quality will not continue to be a source of concern and questions.[33,37]

The naval organizations of the world also developed enclosed spaces in their surface ships. Significant improvements in surface vessels occurred in the mid-nineteenth century and many innovations appeared in the military hardware of the American Civil War. These included iron-clad ships; large, powerful naval guns; and revolving, armored gun turrets. Improvements in surface war ships continued, and by World War I, combatants were engaging each other in very large, massively armored, and heavily armed battleships that became known as dreadnoughts. Before the start of World War I, the German Navy experienced problems with "nitrous fumes" filling the confined space inside naval gun turrets when the gun breech was opened for reloading. The gunners were overcome by the irritant gas, and for protection, they wore respirators. The gases causing the problem were probably a mixture of nitric oxide (NO) and nitrogen dioxide (NO_2). The protective masks that were used, consistent with the practice of the day, probably contained soda–lime and activated coconut shell charcoal. While wearing the masks, the gunners were alleged to have developed methemoglobinemia, with deaths occurring. Evidently, the masks did not remove NO and may have actually increased the NO content in inspired air through the reduction of NO_2. As a result, beginning in World War I and for a period thereafter, the Germans conducted creative laboratory studies to differentiate the toxic effects of NO and NO_2. This problem was corrected, at least in the U.S. Navy, with technology that emerged in the 1930s. The final result was a compressed-air bore cleaner that evacuated the combustion products in the large gun tubes before the gun breech was opened. However, the presence of NO and NO_2 in military vehicles is still a matter of serious concern, and the toxicities of these two gases are still compared and debated.[34,38–44]

Army Contribution

The tank is the best example of an Army enclosed military space. The tank first appeared on the battlefield in World War I, primarily a product of British ingenuity.[27] William Divall, one of the first tankers to go into battle described the experience in a letter to his sister:

> "The whole crew are at various guns, which break forth in a devastating fire."
>
> "By this time, the fumes from the hundreds of rounds which we have fired, with the heat from the engines and the waste petrol and oil, have made the air quite oppressive and uncomfortable to breathe in. However, those who go down to the land in tanks are accustomed to many strange sensations, which would make an ordinary mortal shudder."[45]

Two other innovations of World War I, an effective, rapidly firing machine gun and warfare chemicals combined with the tank to create dangerous environments filled with carbon monoxide (CO). The CO came from the incomplete combustion of propellant in the machine gun shells. Casualties from CO occurred before and during the war, causing

French military scientists to conduct field studies. Firing the machine gun in a tank with all hatches closed and the motor stopped produced the highest levels of CO.[27]

A commonly used practice for setting up machine gun emplacements on the World War I battlefield created a somewhat different enclosed space that was also extremely hazardous. Machine gunners in a trench, for example, fearing a gas attack, would attempt to use any material available to create an air-tight envelope around themselves and the breech of their machine gun. What they did was to effectively contain the CO in their breathing area. As a result of the CO studies conducted by the French military, the practice of hermetically sealing a machine gun emplacement was forbidden.[27]

World War II brought bigger, more powerful armored fighting vehicles, and the U.S. Army met this challenge by establishing the Armored Medical Research Laboratory at Fort Knox, Kentucky, to deal with the complex issues of this new man–machine interface, including the toxicity of propellant combustion products.[27,30,31] Progress was made in identifying the toxic hazards in World War II armored vehicles, but after the war, the Army Medical Department seemed to forget about this research area.[27] However, questions about armored vehicle habitability did not go away; instead they reached an incredible level of complexity in the early 1980s, as the United States began developing armored fighting vehicles that carried large-bore guns and that were sealed and artificially ventilated so that they could operate on a chemical battlefield. Additionally, these vehicles were to be constructed in such a way that soldiers inside a vehicle that was hit by an enemy shell would have the greatest chance possible of surviving. This meant careful evaluation of the types and quantities of potential toxicants that can be found inside an armored fighting vehicle which has been penetrated by an enemy shell and follow-up of field studies with appropriate bench studies. Considerable work has been done within the Army and under contract, including studies of CO and the oxides of nitrogen. This has been accomplished by the Walter Reed Army Institute of Research, Washington, DC, with certain aspects being addressed by the U.S.ABRDL, Fort Detrick, Maryland, and the U.S.AEHA, APG, Maryland. Vehicles, equipment, and soldiers in the recent Persian Gulf War benefited from these efforts, which are continuing.[25,27,28,30,31,43,44]

Air Force Contribution

Unlike the other services, the U.S. Air Force avoided serious problems very early in the rapid development of air and space technology. In the period between World War I and World War II, military aviators were already looking beyond the stratosphere. However, the physical stressors and oxygen requirements of high-altitude flight forced the early development of the enclosed cockpit or cabin with pressure, temperature, and oxygen control. In most cases, this development shielded the aviator from the toxic hazards of combustion products, fuels and lubricants, aircraft cleaning materials, and anti-icing agents. Nevertheless, a whole host of ground support personnel still faced these hazards; environmental problems, e.g., fuel spills, still occurred; and toxicological assessments remained critical components of accident investigations. In the case of cargo or special function aircraft, the cockpit or cabin did not always afford a high degree of protection from exposure. The best known example of this is the exposure of Operation Ranch Hand personnel to Herbicide Orange (with its dioxin contaminant) in Vietnam. As we enter the era of extended space flight and space stations, the U.S. Air Force may write a new chapter on enclosed military spaces, or perhaps they may only add to the saga started by the submariners.[46–48]

The Future of Military Toxicology

I believe that military toxicology is a distinctly different discipline. It plays a major role in the toxicological assessment of health and environmental hazards associated with substances that are used primarily by the military or that present as an unusual type of exposure as a result of a unique military environment.

What does the future hold for military toxicology? There will continue to be a high level of activity related to the environment because of public concern and significant legislation, and great pressure will be brought to bear to find alternatives to our current animal models. Additionally, there will be increased collaboration and cooperation between the military services in conducting toxicological assessments. However, for the most part, military planners and developers will continue to develop new materials and weapons to gain the advantage, just as they have done since the beginning of time. The problems and issues that I have presented and that have kept us busy since World War II will continue.[13,49,50]

In struggling with many of the programs and problems I have discussed and in preparing this report, I found that military toxicologists are generally not very interested in history nor do they make a great enough effort to preserve their work for posterity. Therefore, I ask you to take the time on a routine basis to ensure that your work will always be accessible in established archives; it will be needed again at some time in the future. Please keep in mind the words of George Santayana, "Those who cannot remember the past are condemned to repeat it."

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